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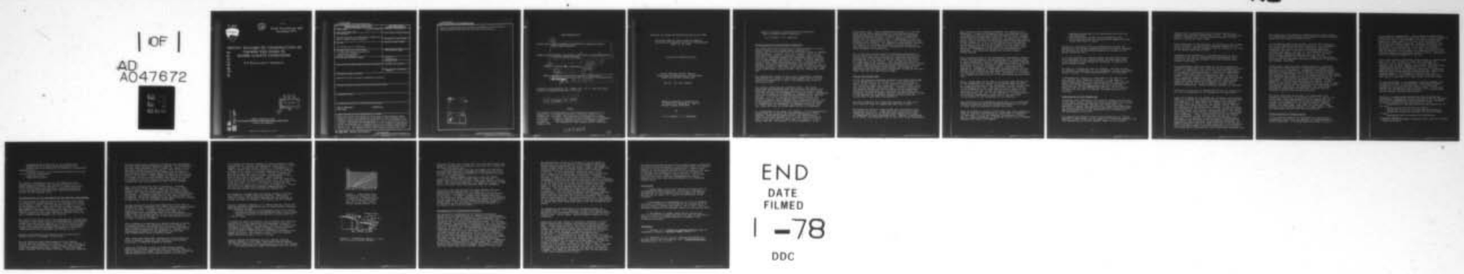

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SPECIFIC FEATURES OF CONSTRUCTION OF THAWED SOIL DAMS IN SEVERE CLIMATE CONDITIONS

G.F. Biianov and L.I. Kudoyarov

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Specific Features of Construction of Thawed Soil Embankment Dams in Severe Climate Conditions

by

G. F. Biyanov, L. I. Kudoyarov

Specific Features of Construction of Thawed Soil Dams in Severe Climate Conditions

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Characteristics of Construction Conditions

The construction area in question is characterized by a continental climate, with average annual temperatures ranging from -8 to -12°C and with the following ranges of temperature variation: diurnal - up to 40°; annual - up to 100°C, universal distribution of permanently frozen rocky and semi-rocky soil, severely eroded to a considerable depth, and subject to considerable settling when thawed. Deluvial deposits along valleys' edges are usually clay with a considerable lime content, containing pieces of bedrock; the thickness of the deposits is usually comparable to the depth of seasonal thawing. Alluvial deposits in the river flood plains contain sand, loam, gravel, and stones, as well as mud. The ice content may reach 60%.

The hydrological regime of the rivers is extremely irregular. The maximum flow occurs in spring and summer, and the winter runoff of the majority of small- and medium-sized rivers is practically zero.

The natural conditions are extremely harsh. The sparse population and remoteness from the inhabited and industrially developed central and southern regions of the country, along with the low level of development of communications, considerably complicate construction organization problems in far northern regions. In view of the lack of roads and railways, the principal role in the transportation picture is played by natural waterways, which usually have a meridional course, and by snowmobiles, but the economic significance of these types of communication is reduced by the seasonal nature of their use, since the time the goods spend enroute is lengthened.

An illustration of the above, for example, is the transportation system used for building the Vilyuysk Hydroelectric Power Station. Construction materials for this hydroelectric power station were shipped by rail to the port of Osetrovo, then up the Lena River to Lensk (990 km), thence by road to Mirnyy (235 km), and finally 110 km by snowmobile to the

construction area. This transportation system, with its seasonal nature and irregular means of transporting materials, required additional portable buildings at the transshipment points and storage of almost a year's supply of materials directly at the construction site. A consequence of the complexity of the transportation system was the considerable loss of materials in transit. The numerous transshipments, reducing the quality of the materials because they were stored for long periods of time, resulted in unavoidable and significant price increases in construction.

All of the above clearly show that hydraulic engineering in the far north must fully utilize local construction materials and minimize long-distance shipments. Hydraulic engineering problems are no less acute in the Far North than they are in any other part of the country. Here the dams must be built to create regulating reservoirs for hydroelectric power stations, tailings dumps of mining and enrichment enterprises, cooling systems of thermoelectric power plants, water supplies for populated areas and industrial enterprises, filling up drainage areas and also for agricultural needs.

Dams of the Thawed Type

One of the principal problems involved in building thawed dams is the deformation of the thawed soil in the foundation as a result of the thawing of the icy inclusions and changes in soil structure, under the influence of the dead weight of the soil and of external loads upon them. Thawing of structural and unstable frozen soil and the change in the temperature regime of the foundation as a result of the developing and continuous process of thermal and mass exchange produces changes in the physical and mechanical properties and throws the reliability of such dams into question.

The best foundation for thawed dams consists of loose soil, which does not lose its supporting power when thawed.

The supporting power of thawed sandy and argillaceous soils containing ice is low. Sandy and gravelly soils lose their supporting capacity to an insignificant degree when thawed in comparison to their nonfrozen state. However, thawed sandy soils differ from nonfrozen ones in that they allow considerably

more settling, which extends throughout the thawing of the foundation. Frozen argillaceous soils, characterized by high total moisture content and extreme cryogenic texture, produce considerable and nonuniform settling. In the case of frozen soils, there is another characteristic phenomenon which occurs during thawing and which is associated with a sharp deformation of the foundation, as well as the settling and irreversible deformation of the soil in the foundation which takes place and is accompanied by a sharp change in its structure, even resulting in squeezing of the soil out from beneath the structure. The filtration properties of soils change during thawing.

These characteristics of dam foundations, prepared by thawing, govern the requirements for dam construction. Building dams on such foundations calls for considerable structural measures to ensure filtration, static, and temperature stability of the foundation and of the structure itself. As in the case of dams built at middle latitudes, special requirements are imposed on foundation preparation, providing antifiltration devices in the foundation, and equipping the body of the dam for drainage, filters, and the like. Therefore, it is natural that thawed dams should be 20 to 25% more expensive than frozen ones.

Hence, thawed dams can be used in situations when deformation of the foundation as a result of its thawing does not lead to a loss of stability of the structure, in other words, when the foundation soil has a low ice content and the settling of the foundation as it thaws does not pose a danger to the stability of the dam, as well as when the thickness of the soil containing ice, left in the foundation, is insignificant, and slightly compressed or loose rock is located close to the surface of the foundation of the structure.

The possibility of constructing thawed dams is often governed purely by questions of water economy and especially by loss of water from the reservoir through filtration.

When the foundation contains soils which lose their supporting power by thawing, construction of thawed dams is impossible. In this case, if it is not possible to construct a frozen dam on a given foundation, a thawed dam can be built if special measures are taken, for example:

- complete elimination of all unreliable soil from the dam foundation;
- pre-construction thawing of the foundation soil;
- other measures aimed at increasing the supporting power of the soil when it thaws.

Frequently, unreliable soils are removed only beneath the central part of the dam, extending through its entire thickness and exposing the antifiltration elements of the dam to the denser foundation soil.

It is also possible to construct heavy drainage "mattresses" with reversible filters, which protect the unreliable soils in the foundation from mechanical suffosion, or devices for sand drainage pilings.

The body of a thawed dam must be flexible and must be able to conform to deformations in the foundation without developing cracks, grooves, or other discontinuities in its structure.

A characteristic feature of thawed dams is the need to take into account their freezing in winter. In the case of insufficient covering of the argillaceous core (less than the depth of seasonal freezing), the latter will be subject to the action of varying temperatures, and soils which are sandy and wet will be deformed and cracked. In this part of the dam, the soil must be covered, for example with a salt treatment.

Requirements for Dam Foundations

Permafrost soil conditions, with seasonal thawing and freezing of the upper levels; varying and often nonsystematic ice content throughout the thickness and over the entire area; the existence of buried ice; different soil temperature conditions; and equally complex engineering and geological conditions pose serious difficulties to the construction of structures and the performance of the work.

The temperature regime of soils in dam foundations is inhomogeneous; in some areas, and on slopes with a northern exposure, the soil temperature is several degrees lower than on southern

slopes, while in the section near the river bed the soil usually has a positive temperature (talik). Deep taliks with positive temperatures are also possible beneath the ocher found in valleys of large rivers.

Dam construction is most difficult on foundations with thermal karst features. In these cases, complete removal of the unreliable soil from the foundation may be necessary or a dam of the frozen type must be built.

Increased water permeability of foundation soils is not an obstacle to the use of thawed dams with appropriate anti-filtration and drainage systems, used when building under ordinary conditions.

The requirements, scope and nature of the work involved in foundation preparation are a function of the "temperature principle" of construction and are not uniform for dams using the frozen and thawed principles. They are also determined by the purpose and service conditions of dams. Thus, for example, the foundations of frozen dams, when in operation, are in different temperature regimes: beneath the core and the lower supporting prism of the dam, they are always frozen; beneath the upper wedge the foundation soil thaws during operation and, as in the upper wedge of the dam, has a positive temperature. Here a different approach is required.

Loose soil can be used in foundations without any limitation, but must be waterproof in the foundations of thawed dams.

Since the stresses in the foundations of medium- and low-head dams do not exceed the limiting strength values characteristic of frozen soil (in some cases they resemble the strength characteristics of loose soil), any frozen friable deposits, even mud, with practically any ice content, can be left in the foundation of the frozen dam. However, it must be taken into account that the icy soil left in the foundation beneath the upper wedge, upon thawing, produces settling; the thawed upper wedge of the dam follows the settling of the foundation and is deformed. Hence, planning must provide for certain extra dimensions to take this settling into account. In addition, it is important to keep in mind the inhomogeneous ice content over the area of the foundation, especially the presence of lenses and other large inclusions of buried ice, whose thawing will result in uneven settling of the foundation and of the upper wedge, which are undesirable not only from the standpoint of esthetics but also could create problems with

the stability of the spillway, especially when, upon thawing, the displacement characteristics are minimal along the boundary separating the thawed and frozen soils.

In constructing dams using thawing, allowing for thawing of soil in the foundation during the operation, the requirements for foundations, as far as their supporting capacity is concerned, are similar to those for building dams under ordinary conditions. The soil in the foundation must have the necessary supporting capacity, must be able to accept loads without deformation and rupture, must be only slightly compressible and stable with respect to ventilation from beneath the equipment, and must be resistant to mechanical and chemical suffosion.

Frozen soils, when they thaw, become capable of filtration but this fact cannot serve as a criterion for judging their suitability in a foundation. By adopting certain structural measures (construction in the foundation of drainage prisms and pilings, "mattresses" etc.) The draining away of melt water and consolidation of the soil in the foundation can be facilitated with possible improvement of the structural properties of such soils. With high and irregular ice content, it may be necessary to replace soil containing clay and/or a large amount of ice, which loses its supporting ability when it thaws. The optimum solution may be found from a detailed study of the engineering, geological, and permafrost soil conditions, followed by development of variations together with the necessary technical and economic analyses.

All other conditions being equal, the requirements for foundation preparation in different parts of the dam may not be the same. More requirements will be imposed upon the quality of the preparation of the dam foundation where it contacts the foundation of the anti-filtration elements beneath the upper wedge, than under the lower one. When preparing the foundation beneath the lower wedge, it often has been found that the work can be minimized.

Winter Covering of Cohesive Soils

In the practical aspects of hydrotechnical construction, considerable effort has been devoted to finding methods of winter protection of the high-grade fill made of soil at

low outside-air temperatures. This problem is particularly complicated in construction under the severe climatic conditions of the Far North. The problems of the entire technological complex are complicated, all the way from organizing the excavation work under conditions involving permafrost and low thickness of useful depth of the mines, the working of the mines, the transportation of the soil with minimum temperature loss, all the way to its most effective utilization by compaction and ensuring the necessary quality of the contacts between the individual layers to obtain homogeneous fill with intensive freezing of the soil.

Under harsh climatic conditions, when outside air temperatures reach -30, 40, or 50°C, a single salt treatment of the soil will be insufficient. At the same time other measures must be used, reducing heat losses over the entire technological network, keeping the soil at a positive temperature until it has completely compacted. Furthermore, when the work is done outside (without heaters) despite the measures used, it is difficult to keep the soil from freezing before it is covered by the next layer, so that each layer is laid down on a layer which is already frozen.

In this connection, it is necessary to employ chemical soil protection to keep it from freezing, using other measures to keep the soil in this state and at a high positive temperature, preparing ditches, working them, transporting the soil to the ditches, and compacting it to ensure good contact between the individual layers.

Recently, a technological complex has been developed and successfully implemented for packing binding soil at extremely low negative temperatures, whose elements are the following production operations from the mine to the site:

- organization of the mine operation and preparation of the soil;
- winter storage of the soil in "burts;"*
- protection of the soil in burts against freezing;
- electrical heating of the burts for winter storage of soil;
- developing burts for winter soil protection;

* "Burts" - metal cylinders to contain earth, set up in fields. Translator's note.

- transportation of the soil to the storage site;
- preparation of ditches before storing the soil;
- thermal and salt working of the surface of a previously compacted ditch;
- bringing the soil to the ditch and covering it so that it will not cool prematurely;
- leveling the soil;
- compacting the soil.

The careful performance of all of the elements of this technological arrangement for carrying out the work will ensure retention of the packed soil in a thawed state until it is finally packed into the ditch, ensuring continuous contact between the individual fill layers and hence high quality of the structure [1,2].

Characteristics of the Organization of the Open-Pit Mine Economy

The useful depth of open-pit mines for binding soils, which are products of bedrock erosion, in the Far North is limited to the usually active layer and does not exceed 0.6 to 1.2 m. The thickness of the layer which thaws in summer depends upon exposure and the population in the area, the lithological composition of the soil, the presence of vegetation in the form of a grass or peat layer, and other factors, and by the end of summer rarely exceeds 1.20 to 1.50 m.

The frozen state of the soil in the mine and the insignificant thickness of the useful layer, the inhomogeneous granulometric composition and moisture content of the soil within the depth of the layer, the short summer season, and the considerable volume of excavation work govern the features of the mine organization and the technology for working the soil.

Working and preparation of binding soils are practically possible only in the summer, as they thaw.

Work on operating these mines begins with the removal of snow and the clearing of the forest. This work usually is carried out with bulldozers in early spring, when the frozen trees are comparatively easy to uproot and can be pushed aside, together with the rubble and snow. The mine, freed of

snow and vegetation, is heated by the spring sun long before the snow cover has been completely removed. In the majority of areas where permafrost soil is found, the amount of heat from solar radiation in spring (April - May) is only 10 to 15% less than the maximum in the summer, and the total radiation during each of these months according to the data is about 13.5 kcal/cm^2. Prompt removal of the snow cover makes it possible to utilize the incident heat more fully to heat the surface of the soil layer so that the amount of heat required to thaw and evaporate the snow will be reduced.

When a soil and vegetation layer is thawed to a maximum depth of 10 to 15 cm, work can begin to remove it. This process requires care, since a time must be selected when thawing still has not spread deeper than the layer suitable for removal. Otherwise, together with the soil containing the vegetation, the thawed mineral soil of the useful layer will be removed. Since the thickness of the useful layer is limited to begin with, this is extremely undesirable.

Further working of the mine and preparation of the loam is carried out with bulldozers as it thaws, the rate usually being 10 to 15 cm a day. The soil which is removed is stored in burts for up to 2 - 3 weeks. During this time, its temperature rises considerably and the moisture content drops. From the drying shafts, the soil is carried by trucks to burts for winter storage, or to the construction site if filling is going on in summer.

Usual methods of protecting soil against freezing in winter in open-pit mines, with retention of natural insulation and construction of artificial heat-insulating coverings in harsh climatic conditions, are ineffective because of the considerable thickness of the permafrost and the fact that binding soils occur in shallow layers.

Under these same conditions, methods for winter working of soils in open-pit mines are less efficient, using steam, electrical, or chemical methods of melting.

Since the collection of soil in winter cannot produce melted soil by direct excavation from the open-pit mine, it must be prepared in summer, piled in burts, and kept there for several months until it is time to bring it to the site.

Heat losses from the soil during its winter storage in burts, transportation, loading, and compaction range from 6° to 10°C depends on several factors (Figure 1). Consequently, in order to ensure that the soil will be at +2 to +3°C when it is added to the ditch, its minimum temperature in the burts must be no less than +12 to +13°C. This was achieved by setting up burts for winter storage, concentrating a great mass of soil into a given volume. When building the Vilyuysk Dam in the summer of 1964, a burt for loam was first built with a volume of 250,000 m^3, 16 to 18 m high, with a natural slope of 1:1.4. The specific surface of such burts does not exceed 0.12 to 0.13 m^2/m^3 (Figure 2). Piling the soil up in large burts promotes homogenization of the moisture content and granulometric composition.

The building of large burts for winter storage of binding soils does not prevent them from freezing. Additional passive, active, and chemical measures must be provided to reduce the depth of freezing of the burts from the surface.

The most efficient approach is to combine passive, active and chemical methods of protecting soil in burts against freezing. These measures include:

- salting the soil in the peripheral areas of the burts;
- electrical heating of the peripheral areas of the burts;
- thermal insulation of the burts by covering them with a layer of foam.

To reduce the depth of freezing, and to improve the electrical conductivity of the frozen soil for subsequent electrical thawing at the periphery of the burt, the soil is given a salt treatment in the mine. Sodium chloride or calcium chloride is distributed uniformly over the surface of the soil (20 to 30 kg/m^2). Then the soil is shifted by bulldozers and pushed into piles, then placed in burts, with its sloping sides covered by a layer 2 to 2.5 m thick.

Passive methods of protecting the soil against freezing include covering it with foam. When using foam to protect soil against freezing, the following must be taken into account:

- the effectiveness of using foam depends upon the correct

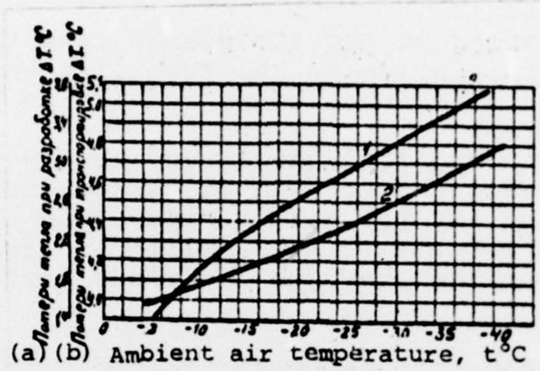

Figure 1. Heat Losses When Working and Compacting Loam. 1, Working; 2, Transportation; (a) Heat Losses During Working, Δt°C; (b) Heat Losses During Transportation, Δt°C.

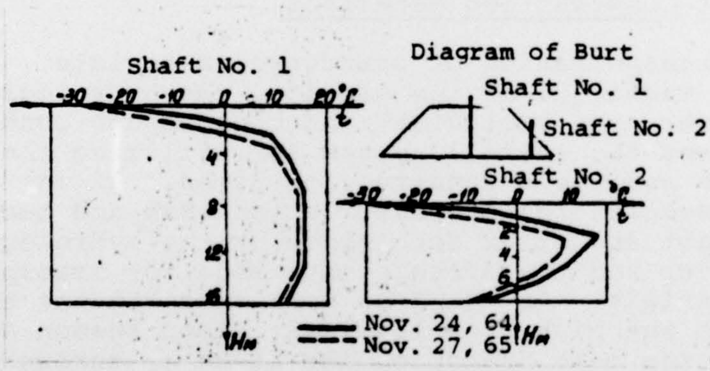

Figure 2. Temperature Regime in a Burt Full of Loam in Winter Storage.

selection of the time to begin work (if work begins early and there is a possibility of thawing, there will be a danger that the foam will settle out);

- preliminary heating of the air pumped into the mixer improves foam formation, increases the stability and life of the foam, and prevents the formation of ice inside the hoses at very low temperatures;

- the freshly prepared foam has a very low thermal conductivity coefficient; hence, when it is applied in a thick layer it will not set for a long time, even in a severe frost. The foam must therefore be applied in layers no more than 10 cm thick, after the previous layer has hardened.

The burts, even when the soil has been treated with salt, freeze from the surface down to a depth of 2 to 2.5 m. Restoration of permafrost is also observed along the bottom of the burts. In order to improve the thermal conditions of the burts as a whole, improving their function and preventing the formation of frozen peaks which reduce the content of frozen lumps in the soil and thereby preventing losses, it is efficient to use electricity to heat the periphery of the burts at 380, 100, and 6000 V.

Transportation of Construction Materials

The system for transportation of structural materials depends upon the magnitude of the amounts, the hydrological regime of the river, the geological and topographic conditions of the section, and the overall system for utilizing the equipment and the available construction times. At the same time, however, organization of construction work and techniques for using equipment are often determined by the hydrological regime of the river and the arrangements made for transporting construction materials. It would be most advantageous to use a system in which the high flow levels at flood season are relieved through the main branch of the river or through a gap in the dam (also possible by letting the water run over the crest of the unfinished dam), and discharging the summer low-water volume and winter flow through water-carrying structures (tunnels, channels, flumes, and pipes). Depending on the stage of completion of the equipment, the system for handling the excess flow can change; for example, initially over the crest, then later through a channel or pipe, etc.

The hydrological regime of the rivers in the Far North is distinctive, due to the physical and geographic conditions (harsh climate, permafrost); up to 85 to 90% of the annual runoff occurs during the spring floods; summer and autumn are characterized by low flow rates, while flow is minimal in winter. In this connection, during low water in the river, dams can be constructed, collecting water higher than the barricade of the construction cofferdam. Favorable factors, in addition to low river flow levels, include the topographic conditions for future reservoirs, making it possible to accumulate river runoff when the dam structure in the riverbed is at its lower levels, as well as the comparatively small amount of work which can be done during a short period of time at a rate which exceeds the water level rise in the reservoir. The diversion of rivers through bypass channels or tunnels is most convenient from the standpoint of work productivity. In this case, structural work can be simultaneously organized over the entire front; this considerably simplifies the techniques for using the equipment, but in the case of construction in non-rocky permafrost soil, this method is not always applicable, especially in the case of construction of frozen dams under conditions under which the foundation has thawed.

In determining the magnitude of the estimated effort for the summer period, it is necessary to take into account the possibility of coincidence of peak rainfall with the so-called "black water," which occurs during intensive thawing of the permafrost.

Experience has been gained in successful discharge of water during construction, through unfinished melted and frozen dams. During construction of the Khantay Hydroelectric Power Station, the autumn and winter water was diverted through a tunnel, while the spring floods were diverted over the crest of the dam, which was given a complete profile up to the halfway mark. The maximum specific consumption was 67 m^3 /sec. In constructing the frozen dam, after the river had been diverted and before the severe frosts came, the profile of the dam was brought up to the halfway mark at a height of 14 m and assembly of the freezing systems began. The dam was frozen and built under a head, and the excess water was allowed to run through two holes in the crest. Thus, this dam, using frozen fill up to the halfway mark for the first time in hydraulic engineering practice, was used for two years as a bypass. The crest of the dam and the foot of the spillway (1:200) were reinforced with stone.

The problem of diverting water when building dams in permafrost soil only arises when working in areas where there are taliks beneath the river, enclosing ground water. However, when working in the excavation for the toe of the core or the apron of the dam, with thawing of soil with high ice content; if measures are not taken to cover this soil and to keep away the melt water, serious consequences may result, preventing the work from being performed at the necessary quality level.

Conclusions

1. Thawed dams, which allow thawing of frozen soils in the foundation during operation, can be built provided the deformations in the foundation due to thawing and thermal settling do not result in a loss of the stability of the structure.

2. Development and implementation of a set of measures will make it possible to build dams out of binding soils in the Far North at temperatures down to -40 to -45°C and to eliminate completely the seasonal nature of construction work.

3. The dumping of excess water during construction over the crest of an uncompleted dam will make it possible to reduce the cost of building expensive temporary water diversion structures.

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